Chandler (C. F.)

# REPORT

UPON THE

# SANITARY CHEMISTRY OF WATERS,

AND

SUGGESTIONS WITH REGARD TO THE SELECTION OF THE WATER SUPPLY OF TOWNS AND CITIES.

BY

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# REPORT UPON THE SANITARY CHEMISTRY OF WATERS, AND SUGGESTIONS WITH REGARD TO THE SELECTION OF THE WATER SUPPLY OF TOWNS AND CITIES.

By. C. F. CHANDLER, Ph. D., M. D., LL. D.,

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THE water supply of towns and cities may be derived from wells, ponds, or rivers.

*Wells* are either shallow or deep. Shallow wells are usually *open*, from ten to sixty or more feet in depth, and from three to ten feet in diameter. Recently, shallow closed "tube" or "driven" wells have become quite popular in many localities. These wells are obtained by driving an iron tube, an inch or more in diameter, into the ground, till a water-bearing stratum is reached. A pump is then attached and a supply of water is pumped up through the tube.

Deep or artesian wells are bored through successive strata often many hundred feet, and even one or two thousand feet deep; the water either flowing from them spontaneously or being raised by pumping.

### I. NATURE OF THE IMPURITIES CONTAINED IN WATER.

1. SPRING WATER. — Water being a great solvent, dissolves to some extent, whatever it comes into contact with. Even atmospheric waters, the rain and melted snow, are not pure. Rain, as it falls through the air, washes out the solid particles of dust, and the germs of animals and plants. And in addition to these it dissolves the oxygen, the nitrogen, carbonic acid and ammonia of the atmosphere, — a greater proportion of the oxygen than of the nitrogen. The air which is dissolved in water is much richer in oxygen than ordinary atmospheric air. The absolute quantity is very small. Twenty-five cubic feet of water take up only one cubic foot of oxygen.

Water which is collected from roofs in the city is never pure. It contains gases which are only developed in cities, sulphur compounds, products of the combustion of coal, chemical operations, etc. After thunder-storms, the rain water is always found to contain minute quantities of nitric acid produced by the electric discharges, which cause the oxygen and nitrogen of the air to unite. Rain water almost always contains a little organic matter, causing it to become putrid when kept for some time.

Terrestrial waters are always impure. Rain falling upon the earth's surface is absorbed by the porous soil, and the materials of which the soil is

composed being to a greater or less extent soluble, the water becomes contaminated with mineral matter. The character of spring water, therefore, depends upon the character of the soil through which it has passed before it issues as a spring. In New England, where the rocks are granitic, and the minerals chiefly quartz, feldspar, and mica, water is extremely pure. But in limestone countries, where carbonate of lime and magnesia abound, we find the spring waters largely contaminated with these substances. These carbonates are rendered soluble in water by the carbonic acid present, which forms bicarbonates with them. To such solutions of bicarbonate of lime are due many curious phenomena in nature.

On boiling solutions of bicarbonate of lime and magnesia, the excess of carbonic acid is expelled, and the carbonates having no longer a solvent are precipitated. In this way incrustations are formed in tea-kettles and steam boilers.

Spring water is generally very clear, although it may be quite impure. It holds its impurities in solution. The soil through which it has passed, although it has conferred upon it its impurities, has at the same time filtered it, and thus rendered it clear and sparkling. As it comes from below the surface, it is generally cool. For these reasons spring water has always been highly prized.

Ordinary spring waters always contain salts of the alkalies and alkaline earths: chlorides, sulphates, and bicarbonates of potassa, soda, lime, and magnesia. The most common salts are the chlorides of potassium and sodium, the sulphates of soda and lime, and the bicarbonates of lime and magnesia.

Besides these alkaline and earthy salts, we almost invariably find silica, the substance of quartz, to the amount of a grain or less in a gallon. The total quantity of dissolved impurities in ordinary spring waters varies from one or two grains to eighty or ninety grains in one U. S. gallon of two hundred and thirty-one cubic inches.

*Hard and Soft Waters.* — Lime salts in water are the cause of what is called *hardness*. They decompose the soap used in washing, forming a flocculent insoluble compound, and destroying its detergent properties. In Glasgow, the saving to the people in soap, due to the introduction of the pure water of Loch Katrine, in place of the hard well waters previously used, is said to amount to one hundred and eighty thousand dollars per annum.

As bicarbonate of lime is destroyed by boiling, with the formation of insoluble carbonate of lime, which does not act on soap, it is said to produce *temporary hardness*, while sulphate of lime, which is not affected by boiling, produces permanent hardness.

*Organic Matter.* — Another impurity which is always present in water, but whose exact chemical character has not been fully determined, is organic matter. This is a collective term for a great many different substances derived from decomposing vegetable and animal matters.

Humic, ulmic, crenic, and apocrenic acids, are the names which have been given to harmless products which result from the decomposition of vegetable

matters, and which are probably always present in spring waters. The objectionable organic matters derived from animal decomposition rarely occur in the waters of springs.

*Living Organisms.* — In addition to the soluble and suspended impurities already mentioned, we find living organisms in water, animals and plants. These animals, when magnified by the microscope, are very frightful in their appearance and motions, but they are not really objectionable. The plants even exercise a purifying influence on the water. It is stated by a celebrated English author, that the providential spread of the American weed *Anacharis Alcinastrum*, has saved thousands of lives by the purifying influence which it has exerted on the water-courses in certain districts in England. These plants liberate oxygen which attacks poisonous dead organic matter and destroys it, thus ridding the water of its most dangerous impurities.

It occasionally happens, however, owing perhaps to some peculiarity of the season, that microscopic animals or plants multiply to such an unusual extent in the waters of lakes or rivers as to produce serious annoyance. This occurred some years ago in the Croton Lake. The subject was investigated by Dr. John Torrey, who reported the presence of myriads of animalcules, which by their death and decomposition communicated to the water a disagreeable taste and odor.

It may be considered as fully established that the ova of entozoa (the eggs or embryos of parasitic worms) gain, sometimes, entrance to the body by the water we drink. We have no reason to believe, however, that the animalculæ in the Croton, Ridgwood, and other city waters of the United States, are such embryos ; or, in fact, that they are in any way objectionable.

In Iceland, however, it is stated that one sixth of the deaths are caused by hydatids in the liver. These are the larval forms of the tænia, or tapeworm of the dog. Young leeches, contained in drinking water, sometimes fix themselves on the pharynx. In a march of the French in Algiers, four hundred men were in the hospital at one time from this cause.

2. Well Water. — Ordinary open wells are supplied partly by springs and partly by surface drainage. The water usually contains the alkaline and alkaline earthy salts of spring water ; the total quantity of mineral matter and the relative proportions of the various salts depending upon the nature of the soil. In the neighborhood of dwellings the proportion of chloride of sodium or common salt is generally increased by the drainage of house refuse, which also leads to the contamination of the water with the products of the decomposition of animal matters such as salts of ammonia, nitrites, and nitrates. In many cases, from the proximity of cesspools and privy vaults, the water becomes contaminated with filtered sewage, matters which, while they hardly affect the taste or smell of the water, have, nevertheless, the power to create the most deadly disturbances in the persons who use the waters.

In the neighborhood of graveyards the water of wells is often impregnated with animal matters from the recently filled graves. As long ago as 1808 it was decreed in France that no one should dig a well within one hundred metres of any cemetery.[1]

[1] See article by Jules Lefort in *American Chemist*, vol. ii., p. 448.

The water of driven wells does not differ in any respect from that of open wells in the same localities, except in cases where there is near the surface a bed of clay or "hard pan," impervious to water. When such a stratum is penetrated by the tube, and the water is drawn from beneath it, the well is somewhat protected from surface drainage.

Artesian wells are in some localities of the greatest economic and sanitary importance, yielding water where it could not otherwise be obtained at all, or pure water, when the shallow surface wells are too impure for domestic use. The former case is illustrated in the Lybian desert, where there are no rivers or springs, and upon which rain never falls: the latter case in the city of London, where the surface wells are contaminated by sewage, while the artesian wells, four or five hundred feet deep, bring up from the chalk beds below a very pure water.

One of the most celebrated fresh water artesian wells is that at Grenelle, a suburb of Paris. It is 1798 feet deep, cost $72,500, and supplies nearly 900,000 gallons daily. The water is received in a reservoir near the Pantheon, and distributed to the adjacent parts of the city.

Deep artesian wells, though free from organic impurities, often contain so much mineral matter as to give them medicinal qualities. This is the case with Dupont's artesian well in Kentucky.

3. Pond, Lake, and River Waters. — Pond, lake, and river waters, although containing the same mineral impurities, are generally purer than spring water, for the reason that while those bodies of water receive the waters of springs, they also receive a considerable quantity of water which has simply run *over* the surface of the earth. When a shower comes up, a portion of the water goes through the soil and issues as a spring; but a large portion of it runs over the soil, and goes into the lakes and rivers without taking with it much mineral matter. For this reason the waters of lakes and ponds are much purer than those of the springs in the same locality. One of the purest waters known is the water of the River Loka in Sweden, which contains only one twentieth of a grain of impurities in a gallon. Rivers are more likely to be charged with *suspended impurities*, foı the reason that their waters, which have not been filtered through the soil, carry with them a certain quantity of mud and organic matter. That is what we see in Potomac water; it has had no opportunity to settle, and has not been filtered out. When water flows into lakes and the sediment subsides, it becomes clear. But in streams where the water runs rapidly, it has no opportunity to deposit its sediment, and it often appears very turbid. The water of the Mississippi contains forty grains of mud per gallon; and it is estimated that this river carries 400,000,000 tons of sediment per annum into the Gulf of Mexico. The Ganges is said to carry down 6,368,000,000 cubic feet annually. This transportation of mud in suspension has produced large deposits at the mouths of these rivers. All of the State of Louisiana, and considerable portions of other States which border upon the lower Mississippi, have been formed by the deposition of these sediments brought from higher levels. This mud is rich in plant food, and the land which it produces is very fertile. The Mohawk flats are famous for their

fertility; and the annual overflow of the Nile is the chief reliance of the poor Egyptians who cultivate the fields enriched by its sediments.

Rivers flowing through populous districts and receiving the drainage of the towns on their banks, often become contaminated with sewage to such a degree as to make them positively offensive, and dangerous to those who drink their water.

The waters of ponds are more largely supplied by springs; they are generally clearer than those of rivers, as the suspended impurities subside. They often exhibit more or less color, due to peaty matters held in solution. This is specially the case in the Dismal Swamp, and in new reservoirs; such matters are entirely harmless.

## II. — EFFECT OF THE IMPURITIES CONTAINED IN WATER.

1. Mineral Impurities. — The quality of the impurities is more important than the quantity. It is found that five or six grains of lime or magnesia render water unfit for the cooking of leguminous vegetables. On the other hand, it is a great advantage in making tea or coffee to use water of about five degrees of hardness; that is, containing about five grains of carbonate of lime or its equivalent in the gallon. A person of very nice taste can tell the difference in tea or coffee made with water in which the difference is not more than two or three grains of lime or magnesia to the gallon. It is on this account that certain wells have a great reputation as "tea wells." In olden times there were two or three such wells in New York, and a boy was kept by the corporation to pump water for the benefit of the natives. The fine flavor of the tea made with such water is due to the fact that the five or six grains of carbonate of lime prevent the water from dissolving the astringent matter contained in the tea, without interfering with the extraction of the theine and the other desirable constituents of the leaf.

Magnesia in large quantities is objectionable, as are also lime salts. They are liable to cause dyspepsia. It is said that horses acquire a rough coat if supplied with water containing a large quantity of sulphate of lime. Goitre and cretinism are attributed to these impurities in the water; at least the facts observed make this reference extremely probable. The goitre appeared in the Durham jail, afflicting a large proportion of the convicts. The spring water with which they were supplied was analyzed, and found to contain seventy-seven grains of lime and magnesia salts per gallon. On substituting for this a water containing only eighteen grains of these salts, it was found that the old cases rapidly improved, while no new cases made their appearance. In the limestone districts of England, Switzerland and central New York, this goitre has been traced over considerable areas. At Goruckpoor, in India, where the waters are quite calcareous, ten per cent. of the adults are afflicted with goitre, and many of the children are cretins. Even the cats and dogs are said to be afflicted with cretinism, which is a kind of idiotic insanity. It is a curious fact that in Ireland, on the Waterford side of the Suir, where sandstones and slates prevail, goitre and cretinism are almost unknown, while on the Kilkenny side, where limestones

abound, goitre is not uncommon. Perhaps the idiotic behavior of those famous Kilkenny cats is attributable to the calcareous impurities of the water with which these unfortunate quadrupeds slaked their thirst.

With regard to the total quantity of impurities admissible in good drinking water, the sanitary congress which met at Brussels decided that water containing more than thirty-five grains of impurity in one gallon is not wholesome, and that there should not be much more than one grain of organic matter. Thirty-five grains is a large quantity for city water, though well waters frequently contain more.

More recent investigations have shown that moderate quantities of these compounds are actually desirable, at least this is claimed by some of the most distinguished authorities in England, where the subject of water supplies for cities has been most carefully studied. Dr. Letheby has carefully examined the connection between the quantities of lime and magnesia salts contained in the waters used in sixty-five English and Scotch cities and towns in connection with the rates of mortality. For convenience of comparison the waters are rated according to their hardness, represented in grains per gallon of carbonate of lime, or its equivalent in soap-destroying compounds.

*Table showing Hardness of the Water Supply and the Death Rate.*

| Hardness. | Number of Towns. | Average Death rate per 1,000. | Average Hardness. |
|---|---|---|---|
| Over 10° . . . . . . | 25 | 21.9 | 16. |
| 10° to 6° . . . . . | 17 | 24.9 | 8. |
| 6° to 2° . . . . . . | 15 | 26.3 | 3.8. |
| 2° and under . . . . | 8 | 28.5 | 1.3. |

It would certainly appear from these figures, that waters containing earthy salts in considerable quantities are preferable to very soft waters. Even if this generalization of Dr. Letheby is not fully sustained, the old theory, which demanded the softest water possible, can hardly stand in opposition to these facts.

2. Organic Matter. — The organic matter of a purely vegetable origin, such as occurs to the extent of one, two, or three grains per gallon, in country springs and wells, or in ponds and rivers, even when it contributes a tint of yellow to the water, is entirely harmless and unobjectionable. The nitrates, nitrites, and ammonia salts found in wells in densely peopled towns are themselves harmless, but their presence proves the contamination of the water with the products of decomposition of animal refuse, and should always be viewed in the light of a warning of the presence of impending danger.

3. Animal Excreta. — The products of the decomposition of animal matter in water, is, however, by far the most objectionable impurity. Organic matters, produced by the decomposition of vegetable substances, are not especially dangerous, but the products of decomposing animal substances

are highly dangerous, even when in minute quantities. These impurities do not make themselves apparent to the taste. On the contrary, such waters are frequently considered unusually fine in flavor, and persons go a great distance to procure them. Nevertheless, they contain an active poison. Many diseases of the most fatal character are now traced to the use of water poisoned with the soakage from soils charged with sewage and excremental matters. Sudden outbreaks of disease of a dysenteric character, are often caused by an irruption of sewage into wells, either from a break in the sewer or cesspool, or from some peculiarity of the season. Such contamination of the water is not indicated by any perceptible change in the appearance of the water. The filtered sewage, clear and transparent, carries with it the germs of the disease. At a convent in Munich, thirty-one out of one hundred and twenty-one of the inmates were affected with typhoid fever. It was found upon investigation that the well was polluted by sewage, and the disease disappeared as soon as the proper repairs were made.

At Pittsfield, Mass., the typhoid fever suddenly broke out in a large boarding-school for young ladies. The water was found to be contaminated with sewage owing to a leak in the cesspool.

At Edgewater, on Staten Island, in 1866, the inmates of a small block of houses were afflicted with typhoid fever, several deaths occurring. On making investigation, the health officers found that a neighbor, through whose land the underground drain passed, had taken the liberty of closing up the drain, thus sending its contents back upon this block of houses, contaminating the well, and thus actually murdering the unfortunate victims with sewer poison.

Dr. Stephen Smith, your distinguished president, describes an interesting case that came to his knowledge. He visited an old schoolmate, a clergyman, in the country, and in the course of conversation his friend told him of a family in which typhoid fever had made its appearance, five members having already died, while another was then fatally sick. The physician called the attention of his friend to the fact that typhoid fever is now attributed to the poisoning of the water by animal refuse. This was new to his friend, the clergyman, who had not thought of attributing it to anything else than to the visitation of Providence. They went together to visit the locality, and found the house situated on an elevation, with all its surroundings admirably arranged for health. One readily believed the statement that there had not been a case of sickness in the house for twelve years. A few weeks before the fever appeared, when the laborers on the farm were busy taking in the crops, one of the valves of the pump got out of order. Being unable to get their usual supply of water, and being too busy to send for the pump-maker, they sent a man down to a neighboring spring to draw water, who finding that it was not easy to dip the water of the spring, from the shallowness of the pool, drew his supply from a brook near by. From this source the family was supplied for two or three weeks. This stream, higher up, ran through several farm-yards and received the surface drainage. The first symptoms of poison by this water were a slight nausea and mild diarrhœa; after several days, typhoid fever in its worst form was ushered in. Of the entire family but two escaped an attack, and they did not use the water.

It is a common saying in villages and towns that "there was health in the old houses, while there is death in the new." This is owing to the fact that when villages were first settled, the houses were supplied with water from the springs on the hill-side, while, as the dwellings multiplied in number, these sources of supply proving insufficient or too distant, wells were sunk in the valley, which, of course, received the drainage of the locality. Hence diseases such as typhoid and typhus fevers, diphtheria, etc., which were unknown to the early settlers, ultimately become prevalent.

I might multiply illustrations without end, of cases in which diseases have been directly traced to impure water. I have here a little diagram which illustrates a case that occurred in the town of Charmouth, in England, a little village situated on the side hill, at the mouth of the Char. The houses are supplied from surface wells, sunk in the gravel and marl.

Typhoid fever broke out. My friend, from whom I obtained the facts, was a scientific man, and knowing that it was not safe to drink the water from these wells, so informed his friends, whom he directed to draw their supplies from the spring above the village. My friend had half a dozen children. Two or three of them were strong enough to manage the pump, and against his express order they drew the water from the well, and drank it. They got the disease as a consequence; but none of the children who could not use the pump, and none of the neighbors who drew water from the springs, were affected.

This city, during the last century, and before the introduction of sewers or the Croton water, was ravaged every few years by deadly epidemics, which are now believed to have been favored and invited by the defilement of the wells then in use, by sewage and fæcal soakage. No such visitation has occurred since the introduction of the Croton water, and the completion of the very perfect system of sewers.

Cholera, though it does not originate from polluted water, is disseminated chiefly by the aid of wells, and other impure water supplies.

At Exeter, England, in 1832, one thousand deaths occurred from cholera.

A purer supply of water was then introduced from a locality two miles higher up the river, above the point at which it received the sewage of the town. When the cholera again invaded the city in 1849, only forty-four cases occurred, and in the cholera season of 1854, there was hardly a case.

In London, in 1854, the water supplied by the Southwark Company contained much sewage, while that supplied by the Lambeth Company was very pure. Both companies had pipes in the same streets, supplying water indiscriminately on both sides. Among those who used the Southwark water, the deaths amounted to one hundred and thirty in 10,000, while among those who drank the Lambeth water, they amounted to only thirty-seven in 10,000; 2,500 persons were destroyed by the Southwark water in one season. On the previous visitation of 1848-49, the case was the reverse. The deaths from the Lambeth amounted to one hundred and twenty-five, while those from the Southwark amounted to one hundred and eighteen in 10,000. At that time, the Lambeth company took their water from a point lower down the river.

Another very striking instance occurred in London. The famous Broad Street pump supplied water in one of the most fashionable localities of the West End. During the visitation of 1848–49, this pump killed five hundred persons in a single week, by disseminating cholera. The wealthy people of the West End went to Brompton, a fashionable summer resort, about five miles up the Thames, and soon the cholera broke out among them there. The health officers soon discovered, on investigation, that these people had been in the habit of sending to the Broad Street pump for tea-water, and had brought the cholera with it. A curious case was that of an old spinster, who had moved to Hampstead, three miles from the pump, but who sent her maid daily, for a kettle of the highly-prized tea-water. She and her maid were the only persons who suffered from cholera at Hampstead.

A similar story might be told of an outbreak of cholera in a shanty village, west of Central Park, and another in a shanty village on the heights across the river. In both cases, it was clearly shown that the cholera germs were distributed among the unfortunate squatters by the waters of the single well in each village. There is a famous pump in the twelfth ward of Brooklyn, at the corner of Van Brunt Street, from which over fifty families obtained their water supply. In 1866 cholera broke out in five or six of these families, but the spread of the disease was prevented by the prompt action of the health officer, who removed the pump handle.

From these facts, it is seen that water aids in disseminating two of the most fatal diseases which affect the human race: the typhoid fever and the deadly cholera. During the ten years from 1856 to 1866, there were 21,000 deaths from cholera in England and Wales, and 150,000 deaths from typhoid fever. There is every reason to believe, that at least three fourths of these deaths might have been prevented had proper attention been paid to the purity of the water supply. This poisoning by bad water is now fully established, and must awaken communities to the vital importance of securing a pure and unfailing supply of this indispensable beverage.

### III. THE SPONTANEOUS PURIFICATION OF RIVER WATER.

While the animal matters which find their way into wells from cesspools and privies are capable of producing the fatal results to which I have called your attention, it is now well settled that such matters are speedily oxydized and destroyed, and thus rendered harmless, when they flow into running streams, by the oxygen held in solution in the water. Dr. Alfred Taylor stated before the Parliamentary Commission, that "organic matter in water is only offensive while in process of decay; when this operation is completed it ceases to be offensive."

Sewage which would poison an ordinary well, becomes harmless in the running stream, and while the well is always open to suspicion, the river, though it drain populous districts, will, nevertheless, supply wholesome water. Having recently had occasion to study this question in connection with the project for supplying the city of Albany from the Hudson River, I have collected some facts and opinions which I will present to you, as embodying the views of the most recent investigators of this subject.

*The Water of the Hudson River.* — The suspended impurities which rendered the water turbid, being temporary in character, were allowed to subside; the clear water was then found to contain the following substances in one United States gallon, of two hundred and thirty-one cubic inches. An analysis of the Croton water is presented at the same time, for comparison.

*Analysis of the Water.*

| | Hudson River. | Croton River. |
|---|---|---|
| Chloride of Sodium | 0.361 grains. | 0.402 grains. |
| Chloride of Magnesium | 0.161 grains. | – |
| Sulphate of Potassa | 0.076 grains. | 0.179 grains. |
| Sulphate of Soda | – | 0.260 grains. |
| Sulphate of Lime | 0.980 grains. | 0.158 grains. |
| Bicarbonate of Lime ($CaO,HO,2CO_2$) | 4.165 grains. | 2.670 grains. |
| Bicarbonate of Magnesia ($MgO,HO,2CO_2$) | 1.397 grains. | 1.913 grains. |
| Silica | 0.408 grains. | 0.621 grains. |
| Alumina and Oxide of Iron | 0.070 grains. | a trace. |
| Organic and Volatile Matter | 0.699 grains. | 0.670 grains. |
| Total | 8.313 grains. | 6.873 grains. |
| Hardness | $3^\circ.35$ | $2^\circ.51$ |

The water of the Hudson has been, and is now, freely used by boatmen and on the steamboats, and by all who are so situated as to make it the most convenient source of supply, and no complaints are known to have been made with regard to its quality, nor has any one suspected it of being in the least unwholesome.

This experience is, however, so limited that it was necessary to seek in other localities for analogous conditions and to satisfy ourselves by comparison, with regard to the probable quality of the Hudson River water. There is no locality in the world to which we could turn with a greater certainty of finding a full array of facts and opinions than have been accumulated in England with regard to the Thames, which supplies more than one half of the water used in London. I therefore instituted a comparison between the two streams in regard to the sources of defilement, volume of water, and natural facilities for aeration and spontaneous purification.

*Extent and Population of the Drainage Area of the Thames.* — The area of the Thames watershed, above the point at which the water companies take their supply, is 3,676 square miles, or 2,352,640 acres, while the population is about one million.

There are three large cities, Oxford, Aylsbury, and Reading, each with a population of over 25,000. The cities next in size are Windsor, Guildford, and St. Albans, containing from 7,600 to 9,500 inhabitants. Besides these there are thirty other towns containing from 2,000 to 7,000 inhabitants each. The average for the entire area is one person to about two and one third acres, or two hundred and seventy-two to each square mile.

The rain-fall in this area averages 27.2 inches, and it is estimated that

one third of this quantity flows down the Thames at Kingston. The average flow at Kingston, for five years, was 1,350,000,000 gallons daily, equivalent to nine inches of rainfall. In very dry seasons, the flow is reduced to 350,000,000 gallons.

*Extent and Population of the Drainage Area of the Hudson River.* — The Hudson River at Albany, including the Mohawk, drains an area of about 7,000 square miles, or 4,500,000 acres, while the population is about 400,000.

On the Hudson there are two large cities, Troy and West Troy, containing 46,421 and 22,616 inhabitants, respectively; and one on the Mohawk, Utica, with a population of 28,798. There are fourteen other cities and towns on the two rivers, with from 2,000 to 15,000 inhabitants each. Still the greater part of the population is scattered in villages, hamlets, and isolated farm-houses.

Very few of these towns are provided with sewers, consequently very little of the unoxydized organic matter of sewage finds its way into the streams. In this respect differing from the English towns on the Thames, where, until recently, the sewage was poured directly into the river.

The average for the entire area is about eleven acres to each inhabitant, or fifty-seven persons to each square mile. The average volume of the Hudson at Albany, was estimated by Mr. Sweet to be 618,111 cubic feet per minute, equal to an average daily flow of 6,677,000,000 gallons. The minimum being 1,829,000,000 in July, and the maximum 12,330,000,000 in March.

*Comparison of the Hudson with the Thames.*

| | Hudson. | Thames. |
|---|---|---|
| Population of the watershed . . . | 400,000 | 1,000,000 |
| Population per square mile . . . . | 57 | 272 |
| Average daily flow . . . . . . . . | 6,677,000,000 gallons. | 1,350,000,000 gallons. |
| Minimum daily flow . . . . . . . | 1,829,000,000 gallons. | 350,000,000 gallons. |

It thus appears that the population of the Thames' area is two and one half times greater than that of the Hudson, and five times more dense, while the flow of the Thames is only about one fifth that of the Hudson. Comparing the population with the flow of the rivers, we find that, in the case of the Thames, it is twelve and one half times greater than in the case of the Hudson.

*Healthfulness of the Thames' Water.* — There have always been alarmists who have excited the fears of the people of London with regard to the condition of the water supply, and there are still those who believe that it is not safe to drink it. From time to time Parliament has caused committees to examine into its condition, and a royal commission has had the matter under consideration for several years. A few quotations from the reports of these bodies and from other sources will serve to show the opinions of those who are most entitled to respect.

*Opinion of the Committee of the House of Commons and the Chemical Commission.* — A special committee of the House of Commons considered the

report of the royal commission of 1850 on the water supply, and employed three of the most distinguished chemists of England to aid them in their investigation. Professor Graham, Master of the mint; Professor W. Allen Miller, and Professor Hoffman. The final verdict of the committee is embodied in the following sentence: "The Thames' water is perfectly wholesome, palatable, and agreeable; uniform, plentiful, and safe in use."

The chemical commission, composed of the chemists above mentioned, reported as follows: —

"As the main drain of a large and populous district, the Thames becomes, at all seasons, polluted by the sewage of several considerable towns, and by the surface drainage of manured and ploughed land; at the same time, we doubt whether the existence of organic contamination from town drainage is at present perceptible in the Thames above the reach of the tidal flow (*i. e.*, above London), or amounts to a sensible evil. The indefinite dilution of such matters in the vast volume of the well aërated stream is likely to lead to their destruction by oxydation, and to cause their disappearance. The river may reasonably be supposed to possess, in its self purifying power, the means of recovery from an amount of contaminating injury equal to what it is at present exposed to in its higher section (*i. e.*, above London.)"

In 1867 another committee of the House of Commons inquired into the water question. After listening to the testimony of a number of the most competent experts they declared that "They were satisfied with both the quantity and quality of the water supplied by the River Thames." The water of the Lea they found "naturally not only wholesome, but comparing favorably with that supplied to other places."

While these extracts represent the general verdict in favor of the Thames water, there were still, and there are even now, a few who dissent from this opinion. The most prominent of these is Dr. Frankland, professor of chemistry at the Royal Institution.

Dr. H. Letheby, the medical officer of health for the city of London, thus criticizes his opinion: —

"In reply to your letter of the 5th instant, I have to state that I cannot agree with Dr. Frankland that the water of the Thames, after receiving defecated sewage water, is unfit for domestic use; for, after a large practical acquaintance with the subject as it is observed in the principal streams and rivers of England, I have arrived at a very decided conclusion that sewage when it is mixed with twenty times its volume of running water and has flowed a distance of ten or twelve miles, is absolutely destroyed; the agents of destruction being infusorial animals, aquatic plants and fish, and chemical oxydation."

Dr. Frankland seems to contradict himself, for in an article in the "Quarterly Journal of Science" of 1867, he says: —

"The population in the basin of the Thames above where water is taken is 1,000,000, the drainage of some 600,000 of whom is poured into the river; the sewage is so thoroughly oxydized that no trace of it can be detected in an unoxidized state. The average flow of the river at the point where the companies take their supply is 800,000,000 gallons daily. The sewage contained would be $\frac{2250}{100000}$."

*Report of the Royal Commission.* — In 1869 the royal commission on the water supply of the metropolis made their last report, which was published in a folio volume of 128 pages, and was accompanied by a volume of minutes of evidence of 488 folio pages, and an appendix of 144 pages with numerous maps, etc. In this report they say: —

"But though for these reasons we believe that the organic contamination of the Thames is much less than is commonly imagined, still it would be sufficient to do great mischief, were it not for a most beneficial provision of nature for effecting spontaneously the purification of the streams. Some of the noxious matter is removed by fish and other animal life, and a further quantity is absorbed by the growth of aquatic vegetation; but, in addition to these abstractions, important changes are effected by chemical action. The organic compounds, dissolved in water, appear to be of very unstable constitution and to be very easily decomposed, the great agent in this decomposition being oxygen, and the process being considerably hastened by the motion of the water. Now, as such waters always contain much air dissolved in them, the decomposing agent is ready at hand to exert its influence the moment the matter is received into the water; in addition to which the motion causes a further action by the exposure to the atmosphere, and when (as in the Thames) the water falls frequently over weirs, passes through locks, etc., causing further agitation and aeration, the process must go on more speedily and more effectually. The effect of the action of oxygen on these organic matters, when complete, is to break them up, to destroy all their peculiar organic constitution, and to re-arrange their elements into permanent inorganic forms, innocuous and free from any deleterious quality. This purifying process is not a mere theoretical speculation. We have abundant practical evidence of its real action in the Thames and other rivers."

In order to present more in detail the opinions of the scientific advisers to the commission, I will present a few extracts from the testimony.

## Extracts from the Testimony before the Commission.

*Testimony of Sir Benjamin Brodie, Professor of Chemistry in the University of Oxford.* — "Oxidization is constantly going on in the soil and in the river; and, therefore, there must be some point at which the perfect destruction or oxidation of its animal matter must take place. What I think is much more important still is another point, namely, the great dilution of the material; and I should rely upon the dilution quite as much, and more, than upon the destruction of the injurious matter; supposing the sewerage of a large town, as Oxford, pouring into the river, there are numerous feeders and tributary streams to the river, which effectively dilute the sewerage. The sewerage is gradually getting less and less, and, therefore, its noxious character diminishes, and ultimately disappears."

*Testimony of Dr. Odling, Professor of Chemistry at the Royal Institute and at St. Bartholomew's Hospital.* — Q. "Has your attention been directed to the important principles of the self-purifying processes which are going on in the rivers running at a given velocity?" A. "Yes, it has." Q.

"You will understand my question is not referring to sluggish waters, but to the rivers where the body of water would become exposed to the action of the atmosphere as it passes along?" A. "You may see in many rivers, even sluggish rivers, having sewerage discharged into them, that for a mile or two the appearance of the river is affected by the sewerage, but beyond a certain distance there is no recognizable effect at all, the weeds are perfectly clear and perfectly healthy."

*Testimony of Dr. Miller, Professor of Chemistry in King's College, London.* — Q. "Are you of the opinion that water once contaminated with sewerage can never be considered a safe water afterwards?" A. "I think experience is quite against that, I think it is safe, evidence shows that it is safe in the majority of instances. There may be cases in which danger is produced." Q. "Have you made any experiments upon the power of water, in a given course, to oxidize organic matter?" A. "I ascertained a remarkable result in 1859 upon the river: I took specimens of the water at Kingston, at Hammersmith, at Somerset House, at Greenwich, at Woolwich, and at Erith on the same day, and I examined the quantity of oxygen which the water contained at all those different points. I found the quantity of oxygen at Kingston was the normal or ordinary proportion; at Somerset House it was much diminished; at Greenwich the whole of the oxygen had disappeared; at Woolwich it was in much the same condition; at Erith it was very much improved, showing that this diminution of oxygen had been produced by the action of the water, contaminated with the sewerage of the London district, and that as it passed lower down the oxygen was again absorbed from the air. And again it became diluted with a large volume of water from below, from other sources, the Lea, the Ravensbourne, and other tributaries, and in this manner the water had again become oxidized. I look upon this as a direct proof of the effect of oxygen in destroying those organic contaminations which are thrown into the river."

*Testimony of Dr. Parkes, Professor of Military Hygiene of the Army Military School at Netley.* — Q. "Have you observed in a case where sewerage has been discharged into a river, that, after running three or four miles, the effect of the sewerage has been destroyed?" A. "Yes, we have that, in the case of the Southampton water supply. Some sewerage passes into the Itchen River, but it is quite destroyed by the time the water is distributed in Southampton, at least there is no detectable quantity." Q. "What is the distance?" A. "The distance is six or eight miles. I could not undertake to state the distance in which water would purify itself in that way, but there is no doubt that it does purify itself, although in what distance, or in what time, or under what precise circumstances, I could not say."

*Testimony of Mr. Leach, Engineer to the Thames Conservancy Board.* — Q. "How soon, in your observation, is the effect of sewerage destroyed by its flow and admixture with the waters?" A. "At Windsor it is discharged into a most unfavorable point in the river, where there is little or no stream at ordinary times. The matter which is passed out of the drain, floats about in the river there to a very great and very disgusting extent. Two miles, or even a mile below, I could see no traces whatever of the sewerage."

*Testimony of Mr. Hawksley, Vice-President of the Institute of Civil Engineers.* — "The great complaint of London water is not the quality of the water itself so much as the polluted district through which it passes. That, I think, there is the greatest possible amount of misconception upon. There is a great deal of prejudice, not unnatural at all, but still amounting to prejudice upon that question. I believe, in fact I know, that the water of the Thames at Hampton is a very excellent water, very pure, very free from organic matter, and that what little organic matter there is, is of a very innocuous character."

Q. "What quantity of water, as compared with the volume of sewerage, is necessary for the purpose of breaking up into its original elements the sewerage which has been discharged into it?" A. "Generally about twenty to one; if the water flows rapidly and is very much disturbed so as to be continually receiving fresh oxygen, a smaller quantity, even twelve to one, will effect the process; if it proceeds very tardily it may take a little more, but usually twenty to one is perfectly abundant."

Q. "You remember, do you not, the original condition of the river at Leicester after receiving all the sewage of the town into it?" A. "Yes, perfectly well; at Leicester the water was as black as this ink; I do not mean to say that it was absolutely so thick, but looking at it in a mass, it was as black as ink; nothing would live in it, and the smell was abominable; but by the time it got to Loughborough, twelve miles below, it was entirely restored to its pristine condition; you could stand on the bridge there and see the fish swimming among the beautiful reedy and other plants growing in the water just as in the purest stream; you could see every pebble at the bottom; that is an instance of the effect of oxidation."

Q. "The water has symptoms of returning purity, has it not, within four miles of Leicester?" A. "Yes, but not to the same extent as at Loughborough; the water was perceptibly impure, at the driest period of the year, down as far as Barrow; it could be just perceived there, but at Loughborough it was perfectly restored."

"There is no such thing as a particle of fæcal matter put into the Thames at Oxford, finding its way down to Hampton Court. It is all burnt up, in fact, by the combustion set up by the oxygen."

THE CHOLERA QUESTION. — It having been established with some considerable degree of probability, that the wells in certain parts of London had aided in disseminating the cholera poison during the successive visitations of that disease to the metropolis, an opinion had gained credence that the water of the Thames had contributed in no small measure to swell the awful list of victims who died from that disease, especially the water supplied by the East London water-works. Considerable testimony was therefore taken upon this point, the most important of which I will quote.

*Testimony of Dr. Robert Argus Smith, Government Inspector of Alkali Works.* — "If the germs pass into the rivers we do not know how far they may be carried. On the other hand we do not know that they ever can be carried in pure water; the dissolved oxygen may destroy them, as it unquestionably does putrescent matters. A positive proof of their transmission, in

otherwise pure water is wanting. One might ask if a cholera germ in the water at Oxford would produce disease in London; and one might answer by asking if one cholera germ passing into the air at Woolwich would produce disease in Pimlico. This we do not know, but it seems probable that disease cannot be carried far by pure air, nor by water with much oxygen in it, which is equal to pure air. We are informed that the atmosphere is full of germs, but the evidence seems to be that it requires an unusual excess to attack us successfully; it seems to be a question of quantity."

*Testimony of Dr. Letheby, Medical Officer of Health to the Corporation of London.* — Q. "Taking the case of the cholera disease and the discharges from the human body being mixed up with the sewage, do you consider that any germs of that disease would be carried down in water?" A. "At the present moment, we do not know what the germs of disease are; if the germs of the disease be decomposing matter, then I do not think that they would exist in the water; but if the germs of the disease be living matter, then it is possible that they may exist in the water; but as nobody, as far as I am informed, can tell us what the germs of cholera are, it would be premature for me or anybody to theorize as to the probability or the possibility of their existing in the water."

Q. "You are aware that it has been alleged that the main cause of the cholera, in the east end of London, was due to the water supply; do you entertain that opinion?" A. "No, I entertain the opposite opinion; it was a matter of duty with me to investigate the whole of the circumstances connected with the East London supply; in the first place it was supplied to the hospital to which I am attached; in the next place it was supplied to the eastern division of the city, where, as officer of health, it was my duty to look well into the matter, and in the third place I had a general interest in it scientifically, apart from any official connection with the subject, and I was very desirous to ascertain whether or not the water had been in any way concerned in the propagation of the disease; I therefore investigated it very fully."

Q. "Do you think the present supply of water to the London people is wholesome water?" A. "I do, a thoroughly wholesome water."

In his report on the sanitary condition of the city of London for the years 1866–67, Dr. Letheby is much more explicit in his discussion of the cholera epidemic of 1866. He says, on page 26, *et seq.*: —

"But difficult as the problem is, to determine the exact value of the several circumstances which influence the severity of the disease, and especially those which give to it its marked local intensities, enough has been ascertained to indicate its general habits, and to show that it fixes itself at low levels in proximity to tidal rivers, among dense populations, that are living in ill-constructed houses, that are filthy, badly ventilated, badly drained, and generally defective of sanitary provisions; and the inference is, that the actual agent of cholera, be it what it may, can only find congenial conditions for its full development in damp and impure air."

"The theory of Pettenkofer is, that the essential conditions for the active manifestations of the disease are a porous soil, charged with excrementitious

matter, and having a certain degree of hydration, as happens when the subsoil water is just drawn off or is slowly retiring. All these conditions were singularly coincident with the localization of the disease in the eastern districts of London; for the soil is gravelly, and therefore very porous to air and water, and it is largely charged with excrementitious matters derived from the local tide-locked sewers. It is also remarkable that for some months before the outbreak of the disease, the subsoil water had been gradually sinking in consequence of the drainage operations that were necessary for the construction of the main low-level sewer, and its branch to the Isle of Dogs. Now, according to Pettenkofer, it is exactly under these circumstances that a district is most liable to choleraic infection."

"Another theory which has been advanced to account for the local character of the outbreak is, that the water distributed to the infected districts was charged with choleraic matter; but, looking at all the facts of the case, it is clearly evident that while none of them are discordant with Pettenkofer's theory, a large number are in open and direct antagonism to the water hypothesis. In point of fact it is necessary for the acceptance of such a speculation, not only that some clear proof should be given of the actual pollution of the water with choleraic matter, but also that the time of the outbreak throughout the infected district was coincident with the distribution of such water, and that it did not notably fail to produce the disease wherever it was sent. It is likewise necessary to show that the disease was strictly confined to the area of such distribution, and that the use of other water was not accompanied with like severe results."

"The alleged pollution of the water rests upon a series of assumptions, many of which are in the highest degree improbable."

"Apart, however, from the improbabilities of these assumptions, it is a fact that the water which is said to have been thus polluted did not produce its effects in the several districts to which it was distributed in anything like uniformity of time or force. Suppose, by way of illustration, that alcohol or arsenic had become mixed with the water, and that on a certain day it was distributed to the public; we should expect to find that the action of the poison was not only manifested at the same time over the whole district of supply, but that it was confined to that district. Not so, however, with the water in question, for although it is not alleged to have been more than once polluted, yet the first effects in the several districts occurred at long intervals; and there were many places to which it was distributed, where there was no sign of the disease; while others, which did not receive the water, were seriously affected."

"The dates of the outbreak of the disease in the districts supplied with the East London water were as follows: Bromley, June 27th; Poplar and Bethnal Green, June 30th; Shoreditch and Mile End, July 7th; Whitechapel, Stepney, and St. George's-in-the-East, July 14th; and the East London Union, July 28th. A month, therefore, elapsed between the first outbreak of the disease in the several districts. It is, moreover, remarkable that, while it was so violent in many of the districts of supply, it was absolutely powerless in others. The death rate, for example, of Bethnal Green was

sixty-three per ten thousand of the population; Whitechapel, seventy-eight; Poplar, eighty-five; and St. George's-in-the-East, ninety-three; whereas the districts of Stamford Hill, Upper Clapton, Walthamstow, Woodford, Wanstead, Leytonstone, Buckhurst Hill, North Woolwich, and Silvertown, were absolutely untouched by the disease, notwithstanding that they received the same water, and at the same time."

"More remarkable still, there were places in the very heart of the cholera field, and others close adjoining it, where the residents received the same suspected water, and used it freely without suffering in the least degree. In the Limehouse School, around which the cholera was frightfully fatal, there were four hundred children who drank the same water as their neighbors, and yet there was not even a case of diarrhœa among them. In the London hospital, which is also in the heart of the cholera field, for it is surrounded by the districts of Whitechapel, Bethnal Green, Mile End, Old Town, and St. George's-in-the-East, there was an average resident population of four hundred and sixty-three persons, and, although they drank freely of the unfiltered East London water, yet there was not a case of illness among them."

"Again, in the eastern division of the city of London, which adjoins the cholera field, the suspected water was supplied to one hundred and sixty-one houses, with a population of about one thousand seven hundred and thirty-two persons, but except in one of these houses (20 Somerset Street), which is on the boundary of Whitechapel, there was not a single death from cholera, and to verify this, I have obtained the addresses of all the persons who died in the cholera ward in Bishopsgate Street. But, besides this, the disease was singularly fatal in places where the suspected water was never used. In Crown Court, Blue Anchor Yard, Whitechapel, where the water supply is from the New River, the mortality was at the rate of two hundred and eighty-four per ten thousand. In Boar's Head Yard, of the same district, which is also supplied by the New River, the death rate was one hundred and ninety-three per ten thousand; and indeed there are eighteen courts in Whitechapel, where none of the East London water was used, and yet, out of an aggregate population of four thousand three hundred and fifty-one persons, there were thirty deaths from cholera, the mortality being at the rate of sixty-nine per ten thousand; that of the whole district being but seventy-seven."

"So that, on carefully examining the facts in their relation to the water theory, we find: —

1. "That there is no proof whatever of choleraic pollution of the water."

2. "That there was no coincidence of time in the appearance of the disease in the several districts supplied with the suspected water."

3. "That numerous districts receiving the same water, but situated at high level, or placed beyond the cholera field, were entirely exempt from the disease."

4. "That even in the very heart of the cholera field, there were places receiving and using the suspected water with impunity."

5. "That other places not supplied with the water, but situated within the infected area, suffered equally with the neighborhood."

"I am far from wishing it to be thought that choleraic matter diffused through water will not produce disease. There is abundant evidence to show that it is often a prolific source of it; but I am anxious, in dealing with a question of so much public importance as the origin of the late epidemic, that none of the facts should be perverted, and that no hasty or ingenious hypothesis, without solid foundation, should take possession of the public mind. In the conduct of inquiries like this, there should be a calm, a full, and a candid examination of the facts; we should endeavor to study the phenomena in a philosophical spirit, and apply to them the tests of sound induction; we should strive also to deduce from them such laws as will not only expose the nature of the malady, but will, at the same time, enable us to treat it successfully. Rash opinions, boldly asserted and tenaciously held, though they may force themselves on public attention, rarely lead to useful results; and while they have their hold on the popular mind they seriously hinder the progress of real knowledge."

These extracts are sufficient to indicate the opinions of the most eminent medical officers, chemists, and engineers who have considered the fitness of the waters of the Thames, for supplying the people of London with wholesome water.

The verdict of the commissioners, after carefully and conscientiously weighing all the testimony presented, is as follows: —

"The only point raised against the Thames water on the ground of organic contamination is of less positive character; it is said that water which has once been contaminated with sewage, may still contain undecomposed organic matter, which, though inappreciable by the most delicate chemical tests, may still exercise prejudicial effects on the human system."

"The strongest form of this objection has reference to some opinions now prevalent, that certain forms of disease, such as cholera and typhoid fever, are propagated by germs contained in excremental matter; and it is conceived possible that when matter of this kind once gets into streams, these germs may escape destruction and long preserve their dangerous character. It is said that no process is known by which such noxious material can be removed from water, and, therefore, it is argued, that water which has at any time been contaminated by sewage is henceforth unsuitable for domestic use. These opinions have been advanced by many eminent men of science; they are worthy of respectful attention, and ought to operate as a constant stimulus to the most searching examination of the state of the water; to the improvement of the modes and means of scientific analysis; and to the diligent collection of medical data as to the effect of the waters upon the public health. But we cannot admit them as sufficiently well established to form any conclusive argument for abandoning an otherwise unobjectionable source of water supply; we are of opinion that there is no evidence to lead us to believe that the water now supplied by the companies is not generally good and wholesome."

This report was made in 1869, and has been before the British public in an accessible form, in all its details, nearly five years, and its conclusions have been generally accepted. The most recent opinion I have seen in print

is contained in a voluntary communication made by Dr. Alfred S. Taylor, the distinguished writer on chemistry, toxicology, and medical jurisprudence, to the secretary of the West Middlesex Water Company, under date of March 7, 1872. He says: "Having during the last twenty-one years made analyses of the water supplied to my house by the West Middlesex Company, and compared it with numerous waters derived from rivers, springs and lakes in England and Scotland, I can confirm Dr. Whitmore's general conclusion that the water is good in quality and perfectly wholesome. This opinion is not based merely on chemical analysis, but on twenty-one years' experience derived from its use for all domestic purposes."

CONCLUSION. — I have selected as our chief basis of comparison the water of the Thames, not only because it had been more carefully studied than any other source of city supply, but because it may be considered an extreme case. Notwithstanding the fact that one half the supply of London, a city of considerably more than three millions of inhabitants, is supplied from it, while the river Lea furnishes nearly all the rest, London was said by Dr. Edwin Lankaster, coroner of Middlesex, to be the *healthiest city in the United Kingdom*. Had I not already presented a much more voluminous paper than I intended, I should refer with some detail to the water supplies of several large continental cities, which are derived from large rivers flowing through much more populous regions, than that from which the Hudson issues, on the banks of many of which are cities much larger than any on this river. Tours is supplied from the Cher; Lyons from the Rhone; Toulouse from the Garonne; Angers and Nantes from the Loire; Paris from the Seine, the Canal d'Ourcq, and the Marne; Berlin from the Spree; Hamburg and Altona from the Elbe. The last named city, which is a suburb of Hamburg, takes its supply from a point eight miles below, when the water has received the drainage of two hundred and thirty thousand people. Most of the above mentioned rivers are among the largest streams in France and Germany, and flow through extensive and densely inhabited districts. Yet we have no reason to believe that there is any *permanent* defilement of the waters.

That there is generally no fear on the part of engineers, and those having charge of water supplies in American cities, is fully shown by the fact that many of our largest cities take water from rivers. Hartford is supplied from the Connecticut; Jersey City and Trenton from the Passaic; Philadelphia from the Delaware and Schuylkill; Washington from the Potomac; Cincinnati and Louisville from the Ohio; and St. Louis, New Orleans, and many other cities from the Mississippi.

### IV. THE POLLUTION OF STREAMS BY THE REFUSE FROM FACTORIES.

It is often suggested that the waters of our rivers are liable to become polluted to a dangerous degree by refuse chemicals from paper factories, woolen mills, print works, and chemical works. While this may undoubtedly be true in some densely populated portions of England, where the factories are numerous and the streams very small, I do not think that for

years to come this source of pollution need be feared in this country. Our rivers are too large and our factories too much scattered; and the importance of turning all waste products to account is made imperatively necessary by the sharp competition which prevails among manufacturers. This latter point is well illustrated by our gas companies, who now derive an important revenue from the sale of their coal tar and ammonia water, offensive products which they formerly allowed to run to waste. The waste products of our most important industries are entirely harmless when diluted with large volumes of water. They consist chiefly of sulphuric and hydrochloric acids, lime, potash, soda, iron and alumina salts, chloride of lime, exhausted dye woods, and soap suds used in scouring wool.

The more powerful, form, when mingled, harmless salts, carbonates, sulphates, and chlorides, which are normal constituents of all river waters. The action of many of these products, if appreciable at all, will be to purify the waters, by oxidizing or precipitating the matters derived from sewage. Salts of iron and alumina are especially efficacious in purifying waters. Alum is often used in the West for clarifying the muddy waters of the streams; a pinch being added to a barrel of the water, which on standing a few hours becomes clear and limpid.

The possibility of objectionable pollution will depend in each case upon the ratio of the refuse matters to the quantity of water in the stream.

Dr. Edward Smith in his "Manual for Medical Officers of Health" states that the contamination of streams by the refuse of factories prevails exceedingly in Yorkshire and Lancashire. The waters of river Irwell, a small stream, present the following differences in composition at their source and below Manchester.

*The Irwell.— Grains of Impurities in One Imperial Gallon.*

| | At Source. | Below Manchester. |
|---|---|---|
| Organic Carbon | 0.1009 | 0.8211 |
| Organic Nitrogen | 0.0175 | 0.2324 |
| Total Nitrogen | 0.0343 | 1.1536 |
| Chlorine | 0.8050 | 6.7410 |
| Hardness | 2.6040 | 16.0440 |
| Total Solids | 5.4600 | 39.0600 |

The examination by the Rivers' Pollution Commission of fifteen samples of waters contaminated by the cotton and woolen mills in Yorkshire, showed the following quantities in one Imperial gallon, which were thrown into the waters of the rivers: —

*Grains of Impurities thrown into each Imperial Gallon.*

| | |
|---|---|
| Organic Carbon | 45.3481 |
| Organic Nitrogen | 7.2198 |
| Nitrogen as Nitrates and Nitrites | 0.0287 |
| Ammonia | 8.1529 |
| Total combined Nitrogen | 14.0105 |

| | |
|---|---|
| Chlorine | 15.3580 |
| Arsenic (computed as metal) | 0.0077 |
| Mineral Matters [1] | 332.3880 |
| Total Solids [1] | 235.9000 |

The commission gave a page in their report of 1871, showing in fac-simile a letter written with the water of the river Calder at Wakefield, which equals in depth of color that from a watered ink, and similar examples might have been made from the river water at Bradford."

A clearer idea can be obtained of the influence of factory refuse on river waters, by comparing the quantities of chemicals used with the quantities naturally contained in the streams.

The Croton water contains in one United States gallon of two hundred and thirty-one cubic inches the following *normal* impurities: —

*Croton Water. — Grains in One U. S. Gallon.*

| | |
|---|---|
| Soda | 0.326 |
| Potassa | 0.097 |
| Lime | 0.988 |
| Magnesia | 0.524 |
| Chlorine | 0.243 |
| Sulphuric Acid ($SO^3$) | 0.322 |
| Silica | 0.621 |
| Carbonic Acid | 2.604 |
| Organic and Volatile Matter | 0.670 |
| Total | 6.395 |

One hundred million gallons of this water are used daily in New York, in which are contained the following quantities of the above mentioned substances in pounds, and in tons of 2,000 pounds.

*Impurities in 100,000,000 Gallons of Croton Water.*

| | Pounds. | Tons. |
|---|---|---|
| Soda | 4,657 | 2.319 |
| Potassa | 1,385 | 0.692 |
| Lime | 14,114 | 7.038 |
| Magnesia | 7,485 | 3.742 |
| Chlorine | 3,471 | 1.735 |
| Sulphuric Acid | 4,600 | 2.300 |
| Silica | 8,858 | 4.429 |
| Carbonic Acid | 37,200 | 18.600 |
| Organic and Volatile Matter | 9,571 | 4.785 |
| | 91,341 | 45.640 |

As the average flow of the Croton River is 400,000,000 gallons daily, there are 365,428 pounds or nearly 183 tons of impurities carried to the ocean daily, by a stream which does not receive any refuse from factories. The

[1] These numbers are incredible, and can hardly be accepted as presented without further explanation. — C. F. C.

Thames at Kingston has an average flow of 1,250,000,000 gallons (Imperial) daily, and the water contains

| | | |
|---|---|---|
| Inorganic Impurities | 19. | grains. |
| Organic and Volatile Impurities | 1.68 | grains. |
| Total per gallon | 20.68 | grains. |

This is equivalent to 3.364.286 pounds or 1,682 tons of 2,000 pounds inorganic matter daily; of this two thirds, or 1,121 tons, are carbonate of lime and 271 tons are sulphate of lime.

At the Arnold Print Works at North Adams, Mass., on the South Branch of the Hoosick, the following quantities of the most common chemicals were used daily: lime, 1¼ barrel; soda ash, 200 pounds; sulphuric acid ($H^2SO^4$), 320 pounds. There were contained in the 43,200,000 gallons of water that flowed daily down the stream: —

| | Pounds. | Tons. |
|---|---|---|
| Lime | 10,793 | 5.396 |
| Soda (NaO) | 2,050 | 1.025 |
| Sulphuric Acid ($H^2SO^4$) | 1,715 | 0.857 |
| Or as combined, — | | |
| Carbonate of Lime | 18,852 | 9.476 |
| Carbonate of Magnesia | 10,342 | 5.171 |
| Sulphate of Lime | 574 | 0.243 |

The Valley Bleachery, on the Woonasquatucket River at Providence, R. I., consumed daily: sulphuric acid, 17 pounds; soda ash, 3,000 pounds; bleaching powder, 1,500 pounds.

The following table gives the most complete exhibit of the character and quantities of chemicals, etc., consumed in a large factory; it shows the average daily consumption of materials of all kinds at the Atlantic De Laine works at Providence, R. I., for the ten months from January 1, 1870, to October 29, 1870. The quantity of wool washed amounted to one thousand nine hundred and twenty-six pounds per day. The flow of the stream was thirty-six million gallons in twenty-four hours.

*Daily Consumption of Chemicals at the Atlantic De Laine Works.*

Wool washed, 1,926 pounds.

| | Pounds consumed. | Grains per Gallon of Water in River. |
|---|---|---|
| Sumac | 291.41 | 0.05665 |
| Hypernic Wood | 43.99 | 0.00855 |
| Turmeric | 73.33 | 0.01425 |
| Logwood | 44.05 | 0.02800 |
| Fustic Wood | 66.04 | 0 01283 |
| Cudbear | 63.91 | 0.01242 |
| Madder | 10.53 | 0.00204 |
| Aniline Colors | 1.17 | 0.00022 |
| Sulphate of Iron | 4.04 | 0.00078 |
| Nitrate of Iron | 88.56 | 0.01721 |
| Muriate of Tin | 29.09 | 0.00565 |
| Stannate of Soda | 43.68 | 0.00849 |
| Sulphate of Copper | 90.12 | 0.01751 |
| Sulphate of Soda | 43.75 | 0.00850 |
| Alum | 23.74 | 0.00461 |
| Cream of Tartar | 9.91 | 0.00192 |
| Prussiate of Potash | 14.13 | 0.00274 |
| Bichromate of Potash | 8.44 | 0.00164 |
| Sulphuric Acid | 136.39 | 0.02651 |
| Soap | 90.12 | 0.01751 |
| Total | 1209.75 | 0.23508 |

Supposing all the materials used to have been allowed to run into this little stream, less than one tenth the size of the Croton, the entire pollution would have amounted to less than one fourth grain per gallon. As a matter of fact a large portion of these substances were fixed upon the goods and sent to market, while one half the entire quantity consisted of dye woods, which are chiefly composed of insoluble cellulose (sawdust and chips). It is not probable that the refuse from this factory added 0.05 grain per gallon to the water of the stream.

During the war it was feared that some attempt might be made to poison the Croton supply of New York. The following figures show how difficult the task would have been. To poison the one hundred million gallons supplied to the city in a single day with strychnine, supposing each pint of water to have received the smallest fatal dose of this alkaloid, one sixteenth grain, would have required 7,285 pounds or three and a half tons of strychnine, a quantity not to be found in all the markets of the world. To procure such a quantity it would be necessary to order an extra supply of *nux vomica* beans from the East Indies, three or four years in advance, to secure their collection by the natives.

Supposing arsenic to have been selected, at the rate of two grains (the fatal dose) to the pint, one hundred and fourteen tons would have been required, with special means to secure its solution in the water.

I do not mean by these remarks to discourage reasonable efforts to protect the purity of our streams, but I would meet the absurd arguments of alarmists who frequently terrify our citizens with exaggerated accounts of imaginary dangers, now from the refuse of factories, now from the imaginary poisons of swamps.

## V. THE CROTON WATER.

Few cities are more fortunate in the quantity and quality of their water supply than are New York and Brooklyn. The Croton water is brought to the city of New York by an aqueduct forty-five miles long, which was completed in 1842, the water having been admitted on the 4th of July of that year. Where the water enters the aqueduct, a dam two hundred and thirty feet wide and forty-five feet high was erected in the Croton River, by which the Croton Lake was formed. This serves as a great reservoir or sedimentary basin.

The *Quantity of water supplied* to the citizens of New York is now one hundred and four million gallons daily. and as the population is now 1,040,000 the supply is one hundred gallons per capita. Mr. Jarvis, the engineer, guaged the river at its lowest period, and found its minimum flow to be thirty-two million gallons daily. In long continued dry weather a deficiency of water occurs, for the simple reason that there is not at present sufficient storage capacity in the reservoirs.

The following reservoirs are in the city: —

| | Gallons. |
|---|---|
| Fifth Avenue reservoir | 20,000,000 |
| The old reservoir in the Central Park | 38,000,000 |
| The new reservoir in the Central Park | 1,000,000,000 |
| Total | 1,058,000,000 |

Equivalent to ten days' supply.

Mr. Craven, formerly chief engineer of the Croton Department, carefully examined the region drained by the Croton and its branches, and found several points at which, by the erection of dams of moderate dimensions, enormous storage reservoirs could be formed. These reservoirs are indicated on the topographical map of the Croton water-shed, copied from the map published by Mr. Craven, which accompanies this paper, by the letters A, B, C, etc. The following table indicates the capacity and other important facts with regard to these reservoirs: —

*Proposed Storage Reservoirs.*

| Reservoir. | Area. | Capacity. | Drainage Area. | Extreme Depth of Dam. | Extreme Length of Dam. | Length of Reservoir. | Distance from Croton Dam. | Elevation above Mean Tide. |
|---|---|---|---|---|---|---|---|---|
| | *Acres.* | *Gallons.* | *Sq. miles.* | *Feet.* | *Feet.* | *Feet.* | *Miles.* | *Feet.* |
| A | 485.00 | 5,211,015,625 | 20.45 | 64 | 1,500 | 12,300 | 9.500 | 390 |
| B | 192.00 | 1,701,835,337 | 15.2000 | [illegible] | 1,700 | 6,000 | 12.750 | 500 |
| C | 730.00 | 6,589,101,562 | 13.7100 | 43 | 1,700 | 16,600 | 14.300 | 550 |
| D | 1008.00 | 9,033,632,812 | [illegible] | 48 | 770 | 21,000 | 20.250 | 500 |
| E | 303.00 | 3,369,206,857 | 20.3700 | 64 | 700 | 7,500 | 23.750 | [illegible] |
| F | 600.75 | 6,120,335,937 | 12.5100 | 20.90 | [illegible] | 10,600 | 15.500 | 560 |
| G | [illegible] | 4,861,035,156 | 20.9045 | 73 | 541 | 12,200 | 18.700 | [illegible] |
| H | 384.67 | 2,490,062,500 | 75.4574 | 40 | 545 | 14,748 | 19.390 | 375 |
| I | 449.00 | 4,205,820,654 | 70.5230 | [illegible] | 331 | 12,745 | 20.447 | 415 |
| J | [illegible] | 2,314,074,703 | 11.9171 | 69 | 1,311 | 11,616 | 28.710 | 500 |
| K | [illegible] | 5,671,449,219 | 78.9000 | [illegible] | 904 | 14,809 | 15.215 | 275 |
| L | 262.75 | 2,328,217,733 | 26.8600 | 74 | 757 | 13,120 | 16.539 | 295 |
| M | 492.25 | 4,392,131,445 | 23.3449 | 72 | 925 | 12,300 | 13.831 | 316 |
| N | 197 00 | 1,676,049,171 | 30.9620 | 60 | [illegible] | 8,650 | 7.708 | 250 |
| O | 239.47 | 2,182,337,109 | 17.3170 | 90 | 1,170 | [illegible] | 9.970 | 305 |

One of the reservoirs planned by Mr. Craven has been constructed at Boyd's Corner, in Putnam County, by General George S. Green. The dam is placed across the west branch of the Croton, twenty three and three-quarter miles from the Croton dam; it is six hundred and fifty feet long and sixty-four feet high, and the reservoir covers an area of three hundred and three acres. It contains 3,369,000,000 gallons of water, a quantity sufficient to supply the city thirty-three days, with its present population. This reservoir alone will carry the city through the longest drought which is liable to occur. As the population of the city increases, it will merely be necessary to construct a new reservoir from time to time. In fact Mr. E. H. Tracy, the present engineer of the Croton Department, is now engaged in constructing a second of these reservoirs, the position of which is indicated on the map.

The aggregate capacity of these fifteen reservoirs is 67,000,000,000 gallons, or two years' supply for the city of New York! It may be asked, Does a sufficient quantity of water fall in the region to fill such a series of reservoirs?

I reply, that the area of the Croton water-shed is $338\frac{82}{100}$ square miles, with an elevation of from two hundred and fifty to six hundred feet above the sea level, and the average rain-fall forty-eight inches. The following table, kindly communicated by Mr. John C. Campbell of the Croton Department, shows the monthly rain-fall at the new reservoir in Putnam County, for the past eight years.

RAIN-FALL. — *Storage Reservoir at Boyd's Corners, Putnam County, New York. From January* 1, 1866, *to January*, 1874.
*Including Melted Snow.*

Altitude of station above tide-level, 600 feet.

| MONTH. | 1866. | 1867. | 1868. | 1869. | 1870. | 1871. | 1872. | 1873. |
|---|---|---|---|---|---|---|---|---|
| January . . | 3.33 | 2.11 | 2.90 | 3.79 | 4.51 | 3.80 | 1.44 | 5.66 |
| February . | 3.60 | 3.00 | 1.38 | 3.64 | 6.40 | 3.81 | 1.22 | 3.09 |
| March . . | 3.33 | 1.49 | 2.55 | 5.48 | 3.80 | 4.27 | 2.59 | 3.08 |
| April . . . | 3.79 | 3.74 | 3.87 | 2.11 | 5.45 | 3.01 | 3.04 | 3.77 |
| May . . . | 5.62 | 6.86 | 8.79 | 4.52 | 2.30 | 3.45 | 3.69 | 2.91 |
| June . . . | 4.45 | 5.28 | 4.53 | 3.59 | 2.06 | 5.73 | 4.00 | 0.71 |
| July . . . | 4.01 | 5.25 | 2.13 | 2.26 | 3.43 | 5.07 | 4.34 | 2.21 |
| August . . | 6.56 | 10.04 | 6.98 | 1.92 | 5.10 | 5.24 | 5.99 | 5.73 |
| September . | 4.92 | 3.62 | 9.33 | 3.20 | 2.85 | 1.44 | 3.69 | 3.73 |
| October . . | 5.09 | 3.66 | 0.87 | 9.46 | 4.73 | 6.18 | 2.15 | 5.13 |
| November . | 3.80 | 3.10 | 4.65 | 2.43 | 2.51 | 4.35 | 4.91 | 3.72 |
| December . | 3.27 | 2.62 | 2.35 | 5.96 | 1.49 | 2.59 | 3.68 | 4.13 |
| Total . . | 51.77 | 60.77 | 50.33 | 48.36 | 44.63 | 48.93 | 40.74 | 39.73 |

Average for eight years . . . . . . 48.15 inches annually.

The following table, for which I am indebted to engineer W. W. Wilson, shows the monthly rain-fall at Sing Sing, and the percentage of water collectable, during the year 1871. The third column exhibits the estimated percentages of rainfall collectable in the valley of the Sprains at Yonkers, N. Y.

*Rain-fall at Sing Sing*, 1871.

| Month. | Rain-fall in inches. | Percentage collected. | Percentage of Sprain collectable. |
|---|---|---|---|
| January | 2.64 | 50 | 18 |
| February | 3.38 | 59 | 59 |
| March | 6.21 | 108 | 158 |
| April | 3.51 | 90 | 93 |
| May | 4.13 | 80 | 99 |
| June | 9.01 | 38 | 18 |
| July | 5.41 | 10 | 7 |
| August | 4.78 | 17 | 15 |
| September | 2.15 | 25 | 40 |
| October | 8.30 | 30 | 28 |
| November | 6.20 | 40 | 77 |
| December | 2.18 | 85 | 85 |
| | 57.90 | 49 | |

From this table it appears that forty-nine per cent. of the rain-fall can be collected and held, provided there is storage capacity to hold it till it is required for use.

Each inch of rain-fall is equivalent to $\frac{5280 \times 5280 \times 144}{231} = 17.378,742$ gallons on each square mile of surface. On the 338.82 square miles of the Croton water-shed each inch of rain would deposit 5,888,165,364 gallons. The forty-eight inches average rain-fall for the past eight years supplied 282,631,-937.472 gallons per annum or 774¼ million gallons daily. Assuming that one half this can be collected, we have an available supply of 387,000,000 gallons daily, or nearly four times our present consumption, a quantity sufficient for four million inhabitants, at the present rate of supply. The present supply of water is very liberal, amounting to 100 gallons per head daily.[1] Imperial Rome received, however, 300 to 340 gallons per head daily.

Few cities at the present day are as liberally provided as New York. The supply of

| | | Gallons. |
|---|---|---|
| Manchester, | in 1852, was | 50 |
| Liverpool, | " 1862, " | 30 |
| Edinburgh, | " 1852, " | 30 |
| Glasgow, | " 1862, " | 50 |
| London, | " 1862, " | 50 |
| New York, | " 1874, " | 100 |
| Imperial Rome | | 300 to 340 |

It has been frequently proposed of late to place water-meters in every building in the city, and tax the citizens in proportion to the quantities of water actually drawn through them. This measure, it is claimed, will prevent the present waste of water. There is an air of justice, too, in the proposition to charge the customers for the water actually used. Persons may be wasteful if they choose, but they must pay for the privilege.

In my opinion, however, this proposition, except as far as it relates to

[1] Besides 12,000,000 pumped from tube (driven) wells, for the use of factories, etc.

factories, breweries, stables, etc., cannot be too strongly condemned. Pure water is hardly second to pure air as a life-giving and life protecting agent. It is the most potent servant the sanitary authorities can call to their aid. To measure out and sell, by the gallon, this bountiful gift of the Creator, would be a crime against the people. It would be in direct opposition to the current of modern civilization, only to be compared, though really a much more serious act, to the tax on windows, which, not a great while ago, compelled people to exclude the blessed light of day from their dwellings, and led architects to adapt their style of architecture to the obnoxious law.

We have already seen that the water-shed of the Croton, with its three hundred and thirty-nine square miles of area, is capable of supplying water for a city of four millions of people, and that the erection of a few dams will secure reservoirs capable of storing this supply. Let the money, then, that would be spent in purchasing costly water-meters, which are five times as expensive as gas-meters, be spent in constructing another of these dams, to give us all the water we need. There is no earthly reason why our water supply should be limited, unless possibly for the benefit of the owner of some patent meter. I speak advisedly on this subject, having been over the ground and seen the sources of supply with my own eyes. We should never consent to see the poor deprived of so essential a source of health and happiness, as pure and abundant water. On the contrary, there is no object for which the public funds can be more legitimately expended, than for increasing the facilities for using water, by the establishment of free public salt and fresh water baths. Why should we of free America, in the nineteenth century, be behind Rome in the days of the Cæsars?

*Purity of the Croton Water.* — The character of the Croton water-shed is of a nature to guarantee water of the best quality. Mountains and hills of Laurentian gneiss receive the rain-fall, which is quickly absorbed and filtered by the pure siliceous sands and gravels, to gush out in numberless springs, feeding the brooks which bear the sparkling waters to the ponds, which serve as natural storage reservoirs. From these flow the large streams, which by uniting form the Croton River. This is finally expanded by the dam at the head of the aqueduct, into a broad deep lake, the *fountain reservoir*, or *Croton Lake*, in which the quiet waters deposit the finer sediments, and thus undergo a final purification before they are admitted to the aqueduct.

Nowhere along the streams can anything be found which can render the waters impure. Rugged rocks or bright green pastures generally border them. A few factories have been located at points where the water power is available, but a careful examination failed to reveal any pollution of the water by them.

Swamps occur in some portions of the water shed, where the waters linger on peaty deposits; but as already stated, from such vegetable matters nothing is taken by the water that can in any way render it unwholesome. At certain seasons of the year, as when the snow melts in the Spring, and the waters scour the still frozen earth, the water is often discolored when it reaches the city, and alarmists begin to discuss the dangers to be appre-

hended from the poisons and miasmata which are derived from the bogs and morasses of Westchester and Putnam counties. But we have never been able to trace any sickness whatever to such sources, and do not believe that any unwholesome impurities ever occur in our water.

The purity of the Croton water is remarkable; if you glance at this diagram, you will see the quantities of the different substances obtained from one United States gallon of two hundred and thirty-one cubic inches, in 1869 and 1872: —

*Solids contained in One Gallon of Croton Water.*

| | Summer, 1869. | May 11, 1872. |
|---|---|---|
| | *grains.* | *grains.* |
| Soda | 0.326 | 0.157 |
| Potassa | 0.097 | 0.109 |
| Lime | 0.988 | 0.819 |
| Magnesia | 0.524 | 0.369 |
| Chlorine | 0.243 | 0.172 |
| Sulphuric Acid | 0.322 | 0.124 |
| Silica | 0.621 | 0.222 |
| Alumina and Oxide of Iron | a trace | 0.058 |
| Carbonic Acid (calculated) | 2.604 | 2.074 |
| Water in Bicarbonates (calculated) | 0.532 | 0.421 |
| Organic and Volatile Matter | 0.670 | 0.874 |
| | 6.927 | 5.399 |
| Less Oxygen, equivalent to the Chlorine | 0.054 | .039 |
| Total | 6.873 | 5.360 |

These acids and bases are probably combined in the water as follows: —

| | Summer, 1869. | May 11, 1872. |
|---|---|---|
| | *grains.* | *grains.* |
| Chloride of Sodium | 0.402 | 0.284 |
| Sulphate of Potassa | 0.179 | 0.205 |
| Sulphate of Soda | 0.260 | 0.024 |
| Sulphate of Lime | 0.158 | 0.024 |
| Bicarbonate of Lime ($CaO,HO,2CO_2$) | 2.670 | 2.331 |
| Bicarbonate of Magnesia ($MgO,HO,2CO^2$) | 1.913 | 1.338 |
| Silica | 0.621 | 0.222 |
| Alumina and Oxide of Iron | a trace | 0.058 |
| Organic Matter | 0.670 | 0.874 |
| Total | 6.873 | 5.360 |

On evaporating a gallon of this water, a residue of only 4.78 grains is obtained, the bicarbonates of lime and magnesia being left as simple carbonates.

The following tabular statement shows how favorably the Croton compares with the waters supplied to other cities.

PURITY OF CITY WATERS.— *Impurities contained in one wine gallon of* 231 *cubic inches, expressed in grains.*

| CITY. | SOURCE. | Inorganic Matter. | Organic and Volatile Matter | Total Solids. |
|---|---|---|---|---|
| New York... | Croton, average for 13 weeks, 1867 (C. F. Chandler)........ | 3.90 | 0.66 | 4.56 |
| New York... | Croton, average for 3 months, 1868 (C. F. Chandler)........ | 3.31 | 1.14 | 4.45 |
| New York... | Croton, average for 6 months, 1869 (C. F. Chandler)........ | 4.11 | 0.67 | 4.78 |
| New York... | Croton, May 11, 1871 (C. F. Chandler)........ | 2.799 | 0.875 | 3.674 |
| New York... | Croton, average for 5 months, winter 1871–72 (E. Waller)........ | 3.934 | 0.508 | 4.442 |
| New York... | Well, west of Central Park (C. F. Chandler)...... | 38.95 | 4.55 | 43.50 |
| Brooklyn .... | Ridgewood, average for 3 months, 1869 (C. F. Chandler)........ | 3.37 | 0.59 | 3.92 |
| Boston ...... | Cochituate (E. N. Horsford) ........ | 2.40 | 0.71 | 3.11 |
| Philadelphia.. | Fairmount, Schuylkill (E. N. Horsford) ........ | 2.30 | 1.20 | 3.50 |
| Philadelphia.. | Delaware (H. Wurtz)........ | 2.93 | 0.55 | 3.48 |
| Albany ...... | Hydrant (E. N. Horsford)........ | 8.47 | 2.31 | 10.78 |
| Troy........ | Hydrant (W. Elderhorst)........ | 6.09 | 1.34 | 7.43 |
| Utica........ | Hydrant (C. F. Chandler) ........ | 5.50 | 0.96 | 6.46 |
| Syracuse .... | New reservoir (C. F. Chandler)........ | 12.13 | 1.80 | 13.93 |
| Cleveland .... | Lake Erie (J. L. Cassels)........ | 4.74 | 1.53 | 6.27 |
| Chicago ..... | Lake Michigan (J. V. Q. Blaney)........ | 5.62 | 1.06 | 6.68 |
| Rochester ... | Genesee River (C. F. Chandler)........ | 12.02 | 1.23 | 13.25 |
| Schenectady .. | State Street well (C. F. Chandler)........ | 46.88 | 2.33 | 49.21 |
| Newark .... / Jersey City. / Hoboken .. / Hudson City | Passaic River (E. N. Horsford)........ | 4.58 | 2.86 | 7.44 |
| Trenton ..... | Delaware River (H. Wurtz) ........ | 2.93 | 0.55 | 3.48 |
| London ...... | Thames (Dr. H. Letheby)........ | 15.55 | 0.83 | 16.38 |
| London ..... | Well, Leadenhall Street (Dr. H. Letheby)........ | 90.38 | 9.59 | 99.97 |
| Dublin ...... | Lough Vartry, new supply (Apjohn and others).... | 1.77 | 1.34 | 3.11 |
| Paris........ | Seine, above the city (Bussey, Wurtz, and Ville)... | 7.83 | 1.00 | 8.83 |
| Amsterdam .. | River Vecht (V. Baumhauer and Van Moorsel) ... | 14.45 | 2.13 | 16.58 |
| Amsterdam... | Deep well at the Keisergracht ........ | 64.55 | 4.38 | 68.93 |

You see by this table that the Croton compares very favorably in purity with the water supplied to other cities. I will call your attention specially to the sixth water on the list, that of the well west of Central Park. This water, you see, contains forty-three and one-half grains of impurities in one gallon, of which over four and one half grains are organic matter. You will not be surprised when I tell you that this well is situated in a shanty village, where cholera was a few years ago extremely fatal.

No one who has ever examined the district which supplies the Croton River will be surprised at the purity of the water as shown by analysis.

## CONCLUSION.

In conclusion I would say that from the facts which I have presented it is evident that wells are always to be viewed with suspicion as sources of water supply, on account of the danger of contamination from the drainage of the soil about dwellings, and of the leakage from drains, cesspools, and privy vaults. Tube or driven wells are little better than open wells. The water of artesian wells is often excellent though sometimes too heavily charged with mineral salts to be available, except for medicinal purposes. For the supply of cities, lakes or rivers must be selected, and although rivers are the great natural sewers, and receive the drainage of towns and cities, the natural process of purification, in most cases, destroys the offensive bodies derived from sewage, and renders them harmless. In very rare cases will organic matters be derived from swamps and peaty deposits, and except that these bodies may sometimes discolor the water there is no sanitary objection to them.

Had time permitted I should have been glad to have discussed the subject of suitable pipes for distributing water in our houses, but this must be left for another occasion.

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